should do away with the acrid yellow character of our fogs. But the mists due to the position of London on the estuary of a large river, would remain to the same extent as now, and there would still be the same amount of sulphurous acid given off into the air to be precipitated with the rain as sulphuric acid, and carry on its work of destruction on building stones and mortar. One cubic foot of coal-gas produces on combustion 0·2 to 0·5 grains of sulphurous acid, so that the amount evolved would continue to be, as now, enormous. Still the air would be deprived of its sooty particles to a great extent, and the old familiar features, characteristic of grimy London, might in time disappear. The carbonic acid which is the chief product in the combustion of coal-gas, is diffused at once into the general body of the atmosphere, and the marvellous rapidity with which this is effected is revealed to us when we know that the air of our open streets and parks differs only by the most minute quantities—if at all—in its contained carbonic acid, from the air of the mountains or the sea.

THE TOPOGRAPHIC FEATURES OF LAKE SHORES[1]

Introduction

THE play of meteoric agents on the surface of the land is universal, and there is a constant tendency to the production of the forms characteristic of their action. All other forms are of the nature of exceptions, and attract the attention of the observer as requiring explanation. The shapes wrought by atmospheric erosion are simple and symmetric, and need but to be enumerated to be recognised as the normal elements of the sculpture of the land. Along each drainage line there is a gradual and gradually increasing ascent from mouth to source, and this law of increasing acclivity applies to all branches as well as to the main stem. Between each pair of adjacent drainage lines is a ridge or hill standing about midway and rounded at the top. Wherever two ridges join there is a summit higher than the adjacent portion of either ridge; and the highest summits of all are those which, measuring along lines of drainage, are most remote from the ocean. The crests of the ridges are not horizontal, but undulate from summit to summit. There are no sharp contrasts of slope; the concave profiles of the drainage lines change their inclination little by little, and they merge by a gradual transition in the convex profiles of the crests and summits. The system of slopes thus succinctly indicated is established by atmospheric erosion under the general law of the interdependence of parts. It is the system which opposes the maximum resistance to the erosive agents.

The factor which most frequently, and in fact almost universally, interrupts these simple curves is heterogeneity of terrane or diversity of rock texture. Different rocks have different powers of resistance to erosion, and the system of declivities which, under the law of interdependence, adjusts itself to diversity of rock texture, is one involving diversity of form. Hard rocks survive, while the soft are eaten away. Peaks and cliffs are produced. Apices are often angular instead of rounded. Profiles exhibit abrupt changes of slope. Flat-topped ridges appear, and the distribution of maximum summits becomes in a measure independent of the length of drainage lines.

A second factor interrupting the continuity of erosion profiles is upheaval, and this produces its effect in two distinct ways. First, the general uprising of a broad tract of land affects the relation of the drainage to its point of discharge or to its base level, causing corrosion by streams to be more rapid than the general waste of the surface, and producing cañons and terraces. Second, a local uprising by means of a fault produces a cliff at the margin of the uplifted tract, and above this cliff there is sometimes a terrace.

A third disturbing factor is glaciation, the *cirques* and moraines of which are distinct from anything wrought by pluvial erosion; and a fourth is found in eruption.

The products of all these agencies except the last have been occasionally confused with the phenomena of shores. The beach-lines of Glen Roy have been called river terraces. The cliffs of the Downs of England have been ascribed to shore waves. Glacial moraines in New Zealand have been interpreted as shore terraces. Beach ridges in our own country have been described as glacial moraines, and fault terraces as well as river terraces have been mistaken for shore marks. Nevertheless, the topographic features associated with shores are essentially distinct from all others; and when their peculiar characters are understood there is little occasion for confusion. It is only where the shore record is faintly drawn that any difficulty need arise in its interpretation. In investigating the history of Lake Bonneville and other Quaternary water bodies of the Great Basin, the writer and his assistants have had constant occasion to distinguish from all others the elements of topography having a littoral origin and have become familiar with the criteria of discrimination. Their endeavour to derive from the peculiarities of the old shore lines the elements of a chronology of the lake which wrought them, has led them to study also the genesis of each special feature.[1]

In the discussion of shore phenomena there is little room for originality. Not only has each of the elements which go to make up the topography of a shore been recognised as such, but its mode of origin has been ascertained. There appears, however, to be room for a systematic treatment of the subject in English, for it is only in continental Europe that its general discussion has been undertaken. The writings of Elie de Beaumont include a valuable contribution,[2] and Alessandro Cialdi has devoted a volume to the motion of waves and their action on coasts.[3] These cover a large portion of the ground of the present essay, but treat the subject from points of view so diverse that the essay would be only partially superseded by their translation. The title of a work by H. Keller ("Studien über die Gestaltung der Sandküsten") indicates another discussion of a general nature, but this I have not seen. American and British contributions are contained chiefly in the reports of engineers on works for the improvement of harbours and the defence of coasts. The most comprehensive which has fallen under my eye, and one, at the same time, of the highest scientific character, is contained in the annual report of the United States Coast Survey for 1869, where Prof. Henry Mitchell, in treating of the reclamation of tide lands, describes the formation of the barriers of sand and shingle by which these are separated from the ocean.

It is proper to add that the writer became acquainted with these works only after the body of this essay was prepared. The objective studies on which his conclusions are based had been completed, and the discussion had acquired nearly its present shape before he became aware of the extent of the affiliated literature. His conclusions have, therefore, the quality of independence, and, so far as they coincide with those of earlier writers, have a corroborative value.

The engineering works whose construction has led to local investigations of shores are chiefly upon maritime coasts, where tides exert an important influence, and the literature of lake shores is comparatively meagre. It is

[1] From a paper by Mr. G. K. Gilbert in the "Fifth Annual Report of the Geological Survey of the United States for 1883-84." (Washington, 1885.)

[1] Partial outlines of the subject have been presented by the writer in connection with various accounts of Lake Bonneville, and a fuller outline was published by Mr. I. C. Russell in a paper on Lake Lahontan in the "Third Annual Report of the Geological Survey."

[2] "Leçons de géologie pratique;" tome premier; septième leçon, "Levées de sable et de galet," pp. 221-52.

[3] "Sul moto ondoso del mare e su le correnti di esso specialmente su quelle littorali pel comm." Alessandro Cialdi. Roma, 1866.

true that the phenomena of lake margins are closely paralleled by those of tide-washed coasts, but this, unfortunately, does not render the literature of the latter the more applicable, for there is a tendency to ascribe to the action of tides features which the students of inland lakes are compelled to account for independently of that agent.

It should be noted also that the point of view of the civil engineer is somewhat different from that of the present study. He is, indeed, concerned with all the forms into which the shore material is wrought by the action of the waves, but he is not at all concerned with their internal structure; and he knows them, moreover, only as subaqueous banks to be determined by sounding, and not at all as features of the dry land. The geologic student has, too, some facilities for study which the engineer lacks, for he is frequently enabled to investigate the anatomy of shore structures by means of natural cross-sections, while the engineer is restricted to an examination of their superficial forms.

Earth Shaping

The earth owes its spheroidal form to attraction and rotation. It owes its great features of continent and ocean bed to the unequal distribution of the heterogeneous material of which it is composed. Many of its minor inequalities can be referred to the same cause, but its details of surface are chiefly moulded by the circulation of the fluids which envelop it. This shaping or moulding of the surface may be divided into three parts—subaërial shaping (land sculpture), subaqueous shaping, and littoral shaping. In each case the process is threefold, comprising erosion, transportation, and deposition.

In subaërial or land shaping the agents of erosion are meteoric—rain, acting both mechanically and chemically, streams, and frost. The agent of transportation is running water. The condition of deposition is diminishing velocity.

In subaqueous shaping, or the moulding of surface which takes place beneath lakes and oceans, currents constitute the agent of erosion. They constitute also the agent of transportation; and the condition of deposition is, as before, diminishing velocity.

In littoral shaping, or the modelling of shore features, waves constitute the agent of erosion. Transportation is performed by waves and currents acting conjointly, and the condition of deposition is increasing depth.

On the land the amount of erosion vastly exceeds the amount of deposition. Under standing water erosion is either *nil* or incomparably inferior in amount to deposition. And these two facts are correlatives, since the product of land erosion is chiefly deposited in lakes and oceans, and the sediments of lakes and oceans are derived chiefly from land erosion. The products of littoral erosion undergo division, going partly to littoral deposition and partly to subaqueous deposition. The material for littoral deposition is derived partly from littoral erosion and partly from land erosion.

That is to say, the detritus worn from the land by meteoric agents is transported outward by streams. Normally it is all carried to the coast, but owing to the almost universal complication of erosion with local uplift, there is a certain share of detritus deposited upon the basins and lower slopes of the land. At the shore a second division takes place, the minor portion being arrested and built into various shore structures, while the major portion continues outward and is deposited in the sea or lake. The product of shore erosion is similarly divided. A part remains upon the shore, where it is combined with material derived from the land, and the remainder goes to swell the volume of subaqueous deposition.

The forms of the land are given chiefly by erosion. Since the wear by streams keeps necessarily in advance of the waste of the intervening surfaces, and since, also, there is inequality of erosion dependent on diversity of texture, land forms are characterised by their variety.

The forms of sea beds and lake beds are given by deposition. The great currents by which subaqueous sediments are distributed sweep over the ridges and other prominences of the surface and leave the intervening depressions comparatively currentless. Deposition, depending on retardation of currents, takes place chiefly in the depressions, so that they are eventually filled and a monotonous uniformity is the result.

The forms of the shore are intermediate in point of variety between those of the land and those of the sea bed; and since they alone claim parentage in waves, they are *sui generis*.

Ocean shores are genetically distinguished from lake shores by the co-operation of tides, which cannot fail to modify the work accomplished by waves and wind currents. The shores which constitute the objective basis of the present discussion were tideless; and the discussion is therefore limited to lake shores. It is perhaps to be regretted that the systematic treatment here proposed could not be extended so as to include all shores, but there is a certain compensation in the fact that the results reached in reference to lake shores have an important negative bearing on tidal discussions. It was long ago pointed out by Élie de Beaumont[1] and Desor[2] that many of the more important features ascribed by hydraulic engineers to tidal action, are produced on the shores of inland seas by waves alone; and the demonstration of wave-work pure and simple should be serviceable to the maritime engineer by pointing out the results in explanation of which it is unnecessary to appeal to the agency of tides.

CAPILLARY ATTRACTION

THE heaviness of matter had been known for as many thousand years as men and philosophers had lived on the earth, but none had suspected or imagined, before Newton's discovery of universal gravitation, that heaviness is due to action at a distance between two portions of matter. Electrical attractions and repulsions, and magnetic attractions and repulsions, had been familiar to naturalists and philosophers for two or three thousand years. Gilbert, by showing that the earth, acting as a great magnet, is the efficient cause of the compass needle's pointing to the north, had enlarged people's ideas regarding the distances at which magnets can exert sensible action. But neither he nor any one else had suggested that heaviness is the resultant of mutual attractions between all parts of the heavy body and all parts of the earth, and it had not entered the imagination of man to conceive that different portions of matter at the earth's surface, or even the more dignified masses called the heavenly bodies, mutually attract one another. Newton did not himself give any observational or experimental proof of the mutual attraction between any two bodies, of which both are smaller than the moon. The smallest case of gravitational action which was included in the observational foundation of his theory, was that of the moon on the waters of the ocean, by which the tides are produced; but his inductive conclusion that the heaviness of a piece of matter at the earth's surface, is the resultant of attractions from all parts of the earth acting in inverse proportion to squares of distances, made it highly probable that pieces of matter within a few feet or a few inches attract one another according to the same law of distance, and Cavendish's splendid experiment verified this conclusion. But now for our question of this evening. Does this attraction between any particle of

[1] "Leçons de Géologie pratique," Paris, 1845, v. i. p. 232.
[2] "Geology of Lake Superior Land District," by Foster and Whitney, Washington, 1851, v. ii. pp. 262, 266.